The Cold Front of 15 April 1994 over the Central United States. Part I: Observations

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ABSTRACT

Detailed observations of the interactions of a cold front and a dryline over the central United States that led to dramatic undulations in the boundary layer, including an undular bore, are investigated using high-resolution water vapor mixing ratio profiles measured by Raman lidars. The lidar-derived water vapor mixing ratio profiles revealed the complex interaction between a dryline and a cold-frontal system. An elevated, well-mixed, and deep midtropospheric layer, as well as a sharp transition (between 5- and 6-km altitude) to a drier region aloft, was observed. The moisture oscillations due to the undular bore and the mixing of the prefrontal air mass with the cold air at the frontal surface are all well depicted. The enhanced precipitable water vapor and roll clouds, the undulations associated with the bore, the strong vertical circulation and mixing that led to the increase in the depth of the low-level moist layer, and the subsequent lifting of this moist layer by the cold-frontal surface, as well as the feeder flow behind the cold front, are clearly indicated.

A synthesis of the Raman lidar–measured water vapor mixing ratio profiles, satellite, radiometer, tower, and Oklahoma Mesonet data indicated that the undular bore was triggered by the approaching cold front and propagated south-southeastward. The observed and calculated bore speeds were in reasonable agreement. Wave-ducting analysis showed that favorable wave-trapping mechanisms existed; a low-level stable layer capped by an inversion, a well-mixed midtropospheric layer, and wind curvature from a low-level jet were found.

1. Introduction

During evenings and early morning hours, the lower atmosphere commonly acts as a waveguide for the propagation of a variety of atmospheric waves that occur in a wide range of both temporal and spatial scales. The undular bore, a propagating disturbance characterized by an abrupt increase in ground-level pressure associated with an increase in ground-level temperature and a shift in wind direction often consisting of wavelike oscillations, is one example that uses the stably stratified layer within the lower atmosphere as a waveguide. Observations of bores have been reported by several authors including Clarke et al. (1981), Shreffler and Binkowski (1981), Smith et al. (1982), Doviak and Ge (1984), Haase and Smith (1984), Simpson (1987), Cheung and Little (1990), Fulton et al. (1990), Koch et al. (1991), Locatelli et al. (1998), Koch and Clark (1999), and others. The Morning Glory, a frequent phenomenon near the Gulf of Carpentaria in northern Australia, reported extensively by Clarke et al. (1981), is an undular bore propagating along a temperature inversion generated by the interaction of a sea-breeze front with a nocturnal maritime inversion.

Several theories have been proposed as possible generation mechanisms for atmospheric bores. Numerical computations of density currents encountering strong stratification near the ground (Crook and Miller 1985; Crook 1986, 1988; Noonan and Smith 1986; Haase and Smith 1989), cool air behind colliding gravity currents (Clarke 1983; Noonan and Smith 1986; Wakimoto and Kingsmill 1995), thunderstorm outflows (Shreffler and Binkowski 1981; Doviak et al. 1989; Fulton et al. 1990), and mesoscale fronts (Smith et al. 1982; Koch et al.

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